tains to the Atlantic coast, severe thunderstorms are not uncommon. On the Great Lakes the severer storms of May advance from the middle-eastern slope of the Rocky Mountains. These storms average about two a month, and their approach is indicated by rapidly falling barometer and east to southeast winds. After the passage of the center of a storm the wind shifts to northwest with rising barometer.

In May the regions in which agricultural products are subject to damage by frost are usually confined to the extreme upper Missouri, and Red River of the North valleys, and the Rocky Mountain and Plateau regions from central New Mexico and the Texas panhandle northward.

SOME CAUSES OF THE VARIABILITY OF EARTHSHINE.

By H. H. KIMBALL.

(Read before the Astronomical and Physical Society of Toronto, June, 1901.)

When we observe the new moon shortly after sunset we are generally able to distinguish the outline of the whole moon, and the dark part is usually of a delicate green tint, or copper color. At the hour of sunset the sun is shining upon the half of the world that is west of us, while the eastern half is shrouded in darkness and night. Between us and the sun in the west is the moon, whose western half is illumined by the sun, but whose eastern half receives no direct sunlight, and is in darkness like the earth, except that its dark half may receive considerable light from the bright half of the earth. This so-called earthshine may vary considerably with the condition of the earth's surface and atmosphere. When the bright half of the earth is covered with snow or cloud it undoubtedly reflects more sunlight than a continent of forest and vegetation, and much more than an ocean of water, and on such occasions the dark half of the moon might be expected to be unusually bright. It is not often that we are able to collect data as to the condition of the atmosphere or of the earth's surface sufficient to satisfactorily explain the variations in the brightness of the dark side of the old moon when seen in the arms of the new.

Mr. G. E. Lumsden, President of the Toronto Astronomical and Physical Society, has requested any information that may be obtainable relative to the condition of the bright half of the earth at 6 or 7 p. m., eastern time, March 22, 1901, which corresponds to 11 p. m. or midnight, Greenwich time, or noon in the middle of the Pacific Ocean. By means of the data given in the Nautical Almanac we ascertain that at Greenwich midnight the sun was in the zenith at about longitude 180°, latitude 0° 40′ north, and the moon was in the zenith at about longitude 132° west, latitude 15° 7′ north. We have therefore prepared, in Chart X, an orthographic projection of the western half of the earth upon the horizon of a point whose zenith is about midway between the sun and moon at this time, namely, latitude 10° north, longitude 160° west. It would have been more correct to have made the projection with the moon in the zenith, but the results would not have differed appreciably from those here given.

Mr. Lumsden writes as follows:

> On the night of the 22d of March the moon, owing to earthshine, was so bright that a member of the Astronomical Society called me up by telephone, and asked me to make observations with the naked eye and an opera glass, with a view to comparison on other occasions. Indeed, I and other members who took the matter up in the course of the evening were surprised at the brilliant illumination, which enabled us to identify, even with the naked eye, certain well known lunar formations. On thinking the matter over, it occurred to me that this brilliancy might have been due to reflection from a very large area of clouded surface, which possibly at the time was true of the western American Continent and the Pacific Ocean, inasmuch as, shortly after midnight, the weather changed, and was succeeded by cloudy skies which lasted for some little time.

Referring to Chart X, and having in mind the positions of the sun and moon at the time specified above, we see that the sun illuminated the half of the globe from longitude 90° west, across the Pacific to 90° east, while the moon could only receive light from the earth's equatorial region as far west as longitude 138° east. Furthermore, while the sun illumined the earth practically from pole to pole, the moon received no light from the antartic regions beyond latitude 75° south. The illumined portion of the earth from which the moon received light, may therefore roughly be stated to lie between latitude 75° south and the North Pole, and longitudes 90° west and 138° east; and Chart X shows that it embraces practically the whole of the Pacific Ocean, the eastern portions of Australia, Japan, and Siberia, and the larger portion of North America—an area that does not differ sensibly, in character or extent, from the normal reflecting surface when the moon is two or three days old, and observed at about 7 p. m. from Toronto.

According to Bond,[1] the quantity of light received at any point by reflection from a surface may be represented by the equation

$$(1) \qquad di' = \theta \frac{\mu\, i}{4\pi} \frac{dp'}{\Delta^2},$$

in which di' may represent the quantity of light received by reflection from the earth upon an element of the moon's surface, ds', projected as dp' upon a plane perpendicular to a line joining the earth and moon; Δ the distance between the earth and moon; μ the albedo of the earth's surface; i the amount of light received by the earth from the sun, which we may assume to be a constant; θ a coefficient that varies with the reflecting properties of the reflecting surface. The value of θ is 1 for a polished sphere, 2 for a flat opaque disc reflecting equally in all directions on the side of the hemisphere toward which it is exposed, 4 for a flat disc in which the quantity of light reflected to any point is proportional to the apparent area of the disc as seen from that point, etc., assuming that the incident rays are parallel and perpendicular. For any given surface, however, this coefficient may be considered a constant, and its exact value does not concern us in the present investigation, since we have to do only with the variables of the above equation. We therefore obtain from equation (1) for the total light received at the moon by reflection from the earth the following expression, in which C is a constant:

$$(2) \qquad i' = C \frac{\mu}{\Delta^2}$$

Similarly, for the light reflected back from the moon to a point on the earth, by substituting (2) for i in (1), we obtain the following equation:

$$(3) \qquad di'' = \theta' C \frac{\mu}{\Delta^2} \frac{dp''\, \mu'}{4\pi\, \Delta^2},$$

in which di'' represents the quantity of light received upon an element of the surface of the earth, projected as dp'' upon a surface perpendicular to a line connecting the earth and moon; θ' is a constant, as in equation (1), and μ' is the albedo for the moon. This albedo must also be a constant, since in the absence of an atmosphere we can not conceive of any variation in the reflecting power of the moon's surface, except the inappreciable variation due to the fact that by reason of libration a slightly different hemisphere is presented to us from time to time.

Our final equation for the quantity of earthshine observed on the moon from a point on the earth will therefore have the following form:

[1] George P. Bond, On the light of the moon and of the planet Jupiter. Memoirs American Academy of Arts and Sciences. 1861. Vol. VIII, p. 233.

$$(4) \qquad i'' = C'' \frac{\mu}{\Delta^4},$$

in which C'' is a constant, and the μ and Δ are variables.

We will now consider the probability of a variation in the value of μ, and its effect upon the intensity of the earthshine on March 22.

Referring again to Chart X, we estimate that the illumined disc of the earth, as seen from the moon, consisted of 15 per cent continent and 85 per cent ocean. The normal distribution of clouds is approximately shown by the lines on Chart X, which are based on the well known cloud charts of Teisserenc de Bort. These show that for the hemisphere we are considering, under average conditions for March, four-tenths of the ground is covered with cloud, and probably two-thirds of the remainder with snow. Over the ocean the average cloudiness is about six-tenths.

The albedos of these various surfaces are not so well determined as we could wish. Bond, in the memoir already quoted, records comparisons between the light reflected from various surfaces, determined principally by means of comparisons with Jupiter. He found, as did Herschel,[2] that the albedo of dry earth, or a rock surface, is about one-sixth that of white paper, or only a little less than that of the moon.

His value for white paper is only 0.410, and is apparently the same as the value determined by Lambert;[3] and his value for newly fallen snow is a little less than that for white paper.

Zöllner,[4] from direct measurements, has given a more satisfactory determination of the albedos of various surfaces, as follows:

Fresh fallen snow, 0.783; white paper, 0.700; white sandstone, 0.237; clay marl, 0.156; moist earth, 0.079; water, 0.021.

These results were obtained with an angle of incidence of 20°. The values vary somewhat with this angle, particularly for a water surface, for which Tyndall[5] gives the following:

Angle of incidence.	μ
°	
0	0.018
40	0.022
60	0.065
80	0.333
89.5	0.721

In the present case we need not concern ourselves about an angle of incidence greater than 20°, except in the case of a tempestuous sea, when the value of μ might greatly exceed that here given, and for cloud surface we may assume μ to have the same value as for white paper. Zöllner's value of the albedo of the moon is 0.1736, which would make that of an ordinary ground surface about 0.16. For a snow surface we can hardly adopt the value he has given, since over North America and Siberia, where the snow surfaces we are considering were lying, the reflecting power must have been much diminished by the presence of forests and bare ground. Furthermore, the surface of the fresh fallen snow soon loses its whiteness from a variety of causes. It will therefore be safer to adopt for the albedo of a snow-clad continent the mean between the albedos of the naked ground and snow, or $\frac{.78 + .16}{2} = 0.47$.

We may therefore deduce the normal average reflecting power of this hemisphere for March, as in the following table:

Proportional parts.			Albedos.	Reflecting power.
Continents... 15	Clouds....	6	0.70	4.20
	Snow......	6	0.47	2.82
	Ground....	3	0.16	0.48
Ocean........ 85	Clouds....	51	0.70	35.70
	Water.....	34	0.021	0.71
Totals.... 100		100		43.91

or an average albedo of 0.44 for the illuminated hemisphere.

The log books of westward bound steamers on the Pacific Ocean on March 22, 1901, are not yet available to any extent, but through the courtesy of the Chief Hydrographer, U. S. N., we have been permitted to examine those of steamers eastward bound and find no evidence of any marked storms or unusual cloudiness over the water at that time. The average cloudiness at Greenwich midnight on March 22, as indicated by these log books, is shown by figures inclosed in circles on Chart X; the figures to the right and a little above the circle indicate the number of observations available for determining these averages. There was, however, an extended area of cloudiness over the western part of the United States, and snow had fallen there during the day. We may therefore increase the cloudiness over the land to seven-tenths and diminish the naked ground to two-tenths, thereby increasing the total in the above table to 44.45, or a little more than one per cent of itself, which would be inappreciable.

It will be interesting to note what would be the effect if the cloudiness over the ocean should be increased materially. We will suppose it to average seven-tenths, and in this case our results will be as follows:

Proportional parts.			Albedos.	Reflecting power.
Continents... 15	Clouds...	7	0.70	4.90
	Snow....	6	0.47	2.82
	Ground..	2	0.16	0.32
Ocean........ 85	Clouds...	59.5	0.70	41.65
	Water...	25.5	0.021	0.54
Totals......100		100.0		50.23

The total reflection in this case is nearly 15 per cent in excess of the average, but we have no data that justifies the assumption of any such increase in the cloudiness on March 22.

It now remains to investigate the effect of the variation in Δ, or the distance between the earth and the moon. The mean distance is about 239,000 miles; the distance at perigee is about 221,000 miles, and at apogee about 253,000 miles. Equation (4) shows us that the intensity of earthshine must vary inversely as the fourth power of these distances, or as 2385 to 3263 for the moon at mean distance and at perigee, and as 4097 to 3263 for the moon at mean distance and at apogee. In other words, the earthshine on the moon is 27 per cent brighter with the moon at perigee than it is with the moon at mean distance, and 25 per cent brighter with the moon at mean distance than it is with the moon at apogee. There is therefore an extreme variation in the intensity of earthshine of 52 per cent, due to the eccentricity of the moon's orbit. This is certainly a greater variation than we could expect from any probable increase or diminution in the average cloudiness over the hemisphere of the earth reflecting light to the moon.

From the Nautical Almanac we find that the semidiameter of the moon at Greenwich midnight, March 8, 1901, was 14′ 45.5″; at noon, March 21, it was 16′ 41.9″; and at midnight, March 22, 16′ 35.7″. On this latter date the moon was therefore just past perigee, and the earthshine should have appeared at least one-fourth brighter than the average.

[2] See pages 276 and 282 of Bond's memoir, above quoted.

[3] See page 282 of Bond's memoir, above quoted.

[4] Dr. J. C. F. Zöllner, Photometrische Untersuchungen. Leipzig, 1865.

[5] Prof. John Tyndall. Six Lectures on Light. London, 1873. Page 17.

The local conditions of the atmosphere have a noticeable effect upon the brightness of the celestial bodies, particularly when they are near the horizon, but apparently only average conditions prevailed at Toronto on the evening of March 22. The air over the United States and Canada had just been cleared of dust by a passing snow and rain storm, but there must have been considerable water vapor present, since the weather became cloudy shortly after midnight, as stated by Mr. Lumsden.

In conclusion, while it is possible that an increase in the cloudiness over the Pacific Ocean may have slighty increased the earthshine on the night in question, we may safely attribute the increased brightness observed to the comparative nearness of the moon at the time.

The new moon will not again be favorably situated for bright earthshine until April, 1902.

Since writing the above article, I find that in the Annals of Harvard College Observatory, Vol. XVIII, p. 75, in an article on the "Total eclipse of the moon, January 28, 1888," Prof. E. C. Pickering has computed the actinic albedo of the moon by the following process, as an illustration of a method that he proposed to apply more completely hereafter:

Two photographs were taken on February 18, 1888, giving for the region of Oceanus Procellarum 0.000015 units or 15 micro-units, if we may use the term. (The unit of light employed is that given out by a Carcel lamp burning pure colza oil and shining through a hole of 1 millimeter radius at the distance of 1 meter for 1 second.) This is equal to 0.000013 times the brightness of the same region during full moon when it is similarly illuminated by the sun. The relative brightness then of the sun and of the gibbous earth one day after it is on the quarter is as 1,000,000 to 13. Adopting Lambert's formula for the illumination of a smooth sphere $L = 1/\pi\ (\sin v - v \cos v)$ where v is the phase angle, we have for the date in question $v = 101° 15'$, whence $L = 0.422''$. [This, therefore, is the relative brightness of the moon for this phase angle regarding the brightness of the earth as unity when it is in opposition; a different result would have been obtained if Professor Pickering had used Zöllner's modification of Lambert's formula.]

From the above it follows that the brightness of the sun is to that of the full earth, as seen from the moon (on February 18, 1888), as 1,000,000 is to 31. The brightness of the sun has been variously estimated visually at from 350,000 to 600,000 times that of the full moon. A photographic determination of mine (Science, VI, p. 133) gave the value as 760,000 or in the ratio of 1.31 to 1,000,000. Adopting the latter figure, we find the full earth 23.6 times as bright, photographically, as the full moon. But the area of the earth is 13.5 times that of the moon, hence its albedo is 1.7 times as great. The portion of the earth illuminating the moon at the time consisted almost exclusively of that portion of the Pacific Ocean east of 160° east longitude, which is generally represented as occupying the Western Hemisphere. As the time of the observations was an afternoon of the rainy season in the South Pacific, it is presumable that a large amount of cloud occupied the visible portion of the torrid zone, while the extreme northern and southern regions were encased in snow and ice; it is therefore not surprising that the factor obtained is so large.

Professor Pickering's actinic albedo for February 18, 1888, when the moon is one day past its quarter, is not essentially opposed to my normal average albedo for March and for the moon three days before the quarter.

HAWAIIAN CLIMATOLOGICAL DATA FOR APRIL AND MAY, 1901.[1]

By CURTIS J. LYONS, Territorial Meteorologist.

GENERAL NOTE.

The mean temperature at sea level was 74.8°, or 0.6° above normal; the highest, 84°, and the lowest, 64° (at sea level).

[1] Through the kindness of Mr. Curtis J. Lyons, a general statement of weather conditions on the Hawaiian Islands may be expected to be furnished regularly for the MONTHLY WEATHER REVIEW. His memorandum for the current month is contained in the following lines.

The rainfall data for the Hawaiian Islands is published quite fully in the Honolulu newspapers in a form that will lead to interesting comparisons between the departures from normal in those islands and the departures in other parts of the world. We reprint the data for April and May, 1901, in conjunction with the annual rainfall for 1900, and hope to give similar tables in the future.—ED.

Rainfall data for the Hawaiian Service.

Stations.	Elevation.	Rainfall. Annual. Normal.	Rainfall. Annual. 1900.	Rainfall. April, 1901.	Rainfall. May, 1901.
HAWAII.					
HILO.	*Feet.*	*Inches.*	*Inches.*	*Inches.*	*Inches.*
Waiakea	50	138.00	111.08	12.85	3.53
Hilo (town)	100	140.00	117.43	12.28	3.10
Kaumana	1,250	....	....	17.31	....
Pepeekeo	100	134.80	87.15	8.94	2.16
Hakalau	200	115.00	102.05	6.48	1.51
Honohina	....	120.00	118.13	8.47	1.56
Laupahoehoe	500	130.00	....	6.16	1.01
Ookala	400	105.00	84.42	....	0.55
HAMAKUA.					
Kukaiau	250	75.00	72.24	2.88	0.29
Paauilo	750	75.00	90.79	4.31	0.14
Paauhau (Moore, Gibb)	300	65.00	49.80	....	0.76
Paauhau (Greig)	1,150	84.00	67.80	2.24	0.17
Honokaa (Muir)	425	76.00	58.08	2.78	0.47
Honokaa (Rickard)	1,900	....	74.25	....	....
Kukuinaele	700	64.00	62.95	2.18	0.40
KOHOLA.					
Awini Ranch	1,100	....	73.65	4.95	....
Niulii	200	51.00	46.36	6.62	0.07
Kohala (Mission)	585	55.00	45.28	3.59	0.44
Kohala (Sugar Co.)	234	55.00	47.32	5.04	....
Waimea	2,720	38.40	37.74	3.82	1.41
Hawi Mill	600	....	40.55	4.51	....
Hawi Mill	300	....	....	4.02	....
KONA.					
Kailua	950	53.30	56.23	10.23	....
Kealakekua	1,580	61.00	64.65	8.86	12.67
KAU.					
Naalehu	650	....	....	3.23	4.79
Honuapo	15	....	25.32	1.92	3.16
Hilea	310	34.00	29.00	3.10	3.10
Pahala	850	42.70	34.76	3.73	3.64
Moaula	1,700	....	....	3.10	....
PUNA.					
Volcano House	4,000	....	63.38	6.78	3.78
Kapoho	110	80.00	80.44	6.12	3.41
Pohoiki	10	81.70	75.10	....	....
Kalapana	8	....	55.06	5.04	3.23
MAUI.					
Olowalu	15	....	18.48	....	....
Waiopae Ranch	700	....	....	2.65	5.52
Kaupo (Mokulau)	285	....	82.34	8.34	8.79
Kahikinui	1,550	....	....	....	7.08
Kipahulilai	300	....	....	14.21	4.98
Namoa Plantation	60	70.00	51.23	2.22	1.98
Nahiku	900	....	....	10.78	3.32
Nahiku	120	....	105.13	6.68	2.85
Haiku	700	....	59.34	10.78	0.80
Kula (Erehwon)	4,500	....	....	1.24	3.10
Puuomalei	1,400	55.00	71.99	2.51	0.78
Paia	180	....	43.97	....	....
Haleakala Ranch	2,000	34.80	54.77	1.10	1.09
LANAI.					
Keomoku	6	....	21.00	0.63	1.16
OAHU.					
Punahou (Weather Bureau)	50	38.40	37.25	3.11	3.23
Kulaokahua	50	30.30	33.21	2.15	2.45
Kewalo (King street)	15	31.40	29.85	2.20	2.67
United States Naval Station	6	....	....	0.66	1.41
Kapiolani Park	10	27.10	17.85	0.95	....
Manoa (Woodlawn D)	285	....	102.53	6.49	7.68
Maakiki Reservoir	....	....	....	3.81	....
School Street (B'shop)	50	40.60	46.25	3.28	3.25
Insane Asylum	30	41.20	33.55	3.41	2.45
Nuuanu (W. W. Hall)	50	40.00	43.95	3.29	....
Nuuanu (Wyllie Street)	250	63.40	69.49	6.15	3.58
Nuuanu (Elec. Station)	450	81.80	....	5.37	....
Nuuanu (Luakaha)	850	132.50	129.21	11.40	13.57
Waimamalo	25	38.90	46.68	2.41	5.30
Maunawili	300	75.20	79.20	8.99	11.59
Kaneohe	100	41.10	64.21	3.49	10.01
Ahuimanu	350	75.20	97.41	....	....
Kahuku	25	32.10	37.21	3.89	3.64
Waialua	20	....	....	2.25	3.19
Wahiawa	800	....	....	3.08	8.14
Ewa Plantation	60	22.77	15.89	2.82	2.36
Waipahu	200	....	....	0.71	3.08
Makiki Reservoir	150	....	....	....	3.43
Kalihi-uka	250	....	....	....	4.83
Moanalua	15	....	....	1.94	2.46
KAUAI.					
Lihue (Grove Farm)	200	42.30	30.86	3.13	8.56
Lihue (Molokoa)	300	48.80	37.20	3.54	9.75
Lihue (Kukaua)	1,000	....	64.45	6.09	17.02
Kealia	15	....	22.32	2.41	7.80
Koloa	250	....	....	2.00	....
Kilauea	325	76.60	56.88	9.04	7.84
Hanalei	10	93.00	83.93	4.74	6.50
Waiawa	32	....	....	0.20	5.18
Wahiawa, Mount	2,100	....	....	11.20	28.75
Eleele	200	....	....	0.64	3.93

The precipitation on the island of Oahu was about normal for most sections, 3.23 inches at Honolulu, 13.57 inches at Luakaha, near the "Pali." The humidity was the highest average for May in twelve years. On the island of Hawaii, the sugar districts of the northeast coast, Hilo, Hamakua,